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Professor Potter A.M.

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VIII. *On the Aërometric Balance, an instrument for measuring the Density of the Air in which it is situated.* By Professor POTTER, A.M., late Fellow of Queen's College, Cambridge*.

THAT the density of the air is an important element in every discussion of atmospheric phænomena, will at once be admitted; but it will be often maintained also, that we have the means of determining it from observations of the wet and dry bulb thermometers and the barometer. A little reflection will, however, soon convince us that this is not absolutely true, since it supposes a regular constitution of the atmosphere for all localities and all states of the weather, which certainly does not exist. Thus, in a room where many persons have been for some time assembled, the carbonic acid gas coming from their lungs in respiration will increase the density of the air in the room; but this will not affect the thermometer, or in a sensible degree the barometer.

There are many natural localities on the earth where exhalations affect the density of the air, but of which the presence escapes detection by the before-named instruments; and at all places we shall find, on consideration, that the density of the air depends on circumstances not necessarily shown to exist by them. If, for instance, the barometric pressure and the temperature were given, we might still have an *upper* current of wind which had a particular hygrometric state and a particular proportion of its constituent gases, whilst the lower current of wind was of another composition. The varying density of the lower current would clearly not be indicated by the usual meteorological instruments.

These cases would be comprehended in the discussion of the formula $p = k\rho(1 + \alpha\theta^\circ)$ for the relation of the pressure,

* Communicated by the Author.

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density, and temperature of a gas, by the consideration that when it is applied to a mixture of gases, such as the atmosphere, the value of k is different for every variation in the proportions of the elements.

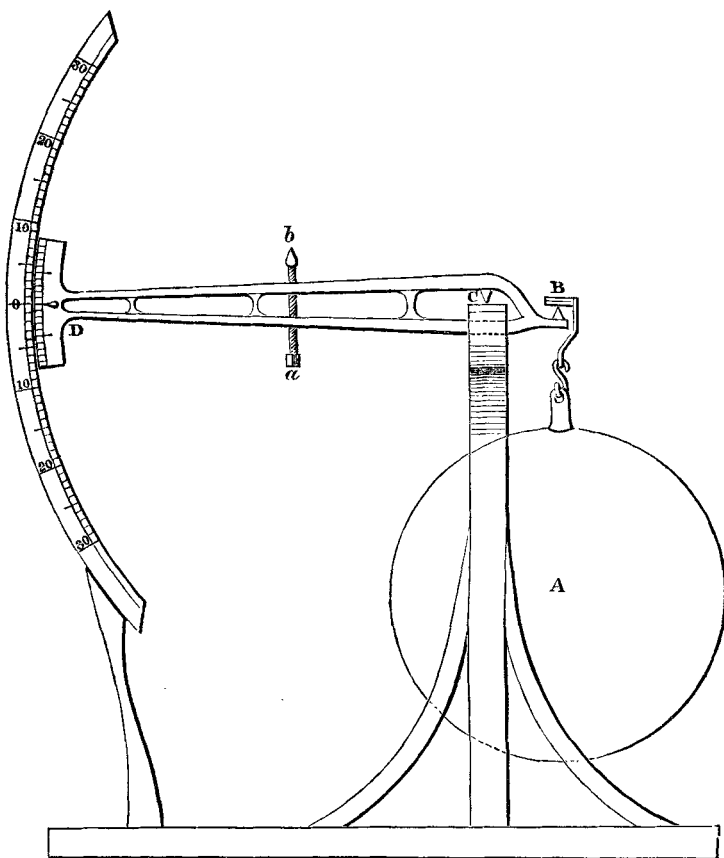
The method of weighing a known volume of the air, which has been admitted into a flask partially exhausted by the air-pump and then weighed, is one of considerable labour, and requiring the greatest degree of care in order to obtain correct results. An instrument which would give the actual density by a simple reading off is evidently so great a desideratum, that the instrument about to be described has probably in some shape or other suggested itself to others, though no instrument of the kind is used at present amongst the recognized meteorological instruments that I am aware of.

The new instrument is a modification of an old air-pump experiment, which is used to show that the greater buoyancy of more bulky over denser bodies of equal weights in the air is a considerable and a measurable quantity. A metallic body hanging at one end of a balance appears in the air to be heavier than a closed hollow globe of glass hanging from the other end; but when placed under the receiver of an air-pump, and the pump is worked, it is soon seen that as the air is withdrawn the apparent excess of weight becomes less and less, and eventually the hollow globe preponderates. In an instrument for determining the variable buoyancy of bodies in the lower stratum of the atmosphere, the points to be sought for in the construction are, a sufficient sensibility and a means of determining the results with readiness. A large closed globe of glass might be weighed at different times in a fine chemical balance; but the process would be tedious, and from perpetual changes in temperature, susceptible of less nicety than that of a delicate bent lever balance, such as I have adopted.

There arise difficulties in the construction when extreme sensibility is desired, which a knowledge of the mechanical properties of balances, and a confidence in their theory, alone can be expected to surmount. For instance, in the trials which have been made with the instrument constructed by Messrs. Watkins and Hill from my drawings, we have found a position of stable equilibrium and another of unstable equilibrium within an angle of 40 degrees. The theory showing that no such positions of equilibrium can exist in a perfect balance, the result indicated that the knife-edges of the balance, or the agate planes in contact with them, though made with all the care considered requisite in fine chemical balances, were yet not sufficiently true for such a degree of sensibility;

and that even with a less degree of sensibility it was requisite to have the knife-edges sharper, straighter, or more nearly parallel, and the agates more accurately flat;—these points were accomplished by improved methods of preparing the parts above named.

The annexed figure is a side view of the essential parts of the instrument. A is a hollow globe of glass of about $4\frac{1}{2}$



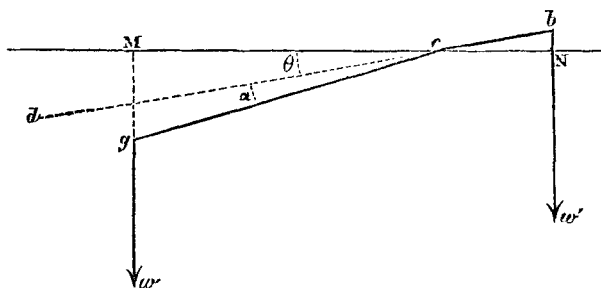
inches diameter, hermetically sealed, having an eye in the upper part where the tube from which it was blown has been sealed: by this eye it is suspended by hooks from a steel stem fixed to the brass frame B, holding an agate plate. This agate plate rests on the knife-edge of the triangular prism of steel as in the figure. C is another triangular prism of steel fixed like the former to the brass lever of the balance. The

knife-edge at C rests on another agate-plate held by the framework of the instrument. The end D of the lever is formed so as to be graduated as a vernier; and a graduated arc having its centre at the knife-edge C is fixed firmly in a vertical plane to the brass framework. The readings of the graduated arc by means of the vernier give the position of equilibrium of the lever. At *a* *b* is a fine steel screw passing through the arm of the lever and carrying a brass head at *b*; this screw, turned by a key, regulates the sensibility of the balance by raising or lowering the centre of gravity of the lever. The spirit-levels for adjustment to the horizontal position, as well as other details, are not drawn in the figure.

The whole balance is fixed firmly in a glass case or lantern, which also contains its accompanying thermometer.

The instrument evidently acts by the changing weight of the air displaced by the globe with its appendages, and the lever. If these volumes were exactly known, and the place of the centre of gravity of that displaced by the lever for given temperatures, then the density of the air could be calculated from the position of equilibrium; but since these cannot be easily determined with accuracy, the method of employing the instrument must be that of finding the value of its divisions in terms of the density of the air, by *experimental methods*, for changes of temperature and pressure; such as by examining the instrument under the receiver of an air-pump furnished with a barometer gauge, and by noting the effect of change of temperature in the lantern when the atmospheric pressure is stationary.

In investigating the theoretical sensibility of the bent lever balance, I shall first suppose, in the ordinary way, that the weights are absolute weights, and afterwards take the modification introduced by supposing the balance used, as actually, in a medium of varying density.



Let *c* be the fulcrum, *b* the point from which the globe and

its appendages hang, their weight being w' ; let g be the centre of gravity of the beam at which its weight w acts; let $cb=r'$, $cg=r$. Drawing the straight lines bcd and cg , let the angle $dcb=\alpha$; also drawing the horizontal line McN , let the angle Mcd ($=$ angle Ncb) $=\theta$.

Then in equilibrium,

$$w \times cM = w' \times cN,$$

or

$$w \times r \cos (\alpha + \theta) = w' \times r' \cos \theta,$$

$$\therefore \tan \theta = \cot \alpha \left(1 - \frac{w'.r'}{w.r.\cos \alpha} \right);$$

let

$$\frac{w'.r'}{w.r} = 1 + x,$$

where x will be a small fraction, positive or negative; we have

$$\begin{aligned} \tan \theta &= \frac{1 - 2 \sin^2 \frac{\alpha}{2} - (1 + x)}{2 \sin \frac{\alpha}{2} \cdot \cos \frac{\alpha}{2}} \\ &= - \tan \frac{\alpha}{2} - \frac{x}{\sin \alpha}. \end{aligned}$$

Here $\theta=0$ when

$$x = -2 \sin^2 \frac{\alpha}{2};$$

also for a given value \pm of x , θ changes very rapidly for corresponding changes in the value of α when this latter is very small: or the sensibility increases very quickly when the points b , c , and g are brought very nearly into one straight line.

Again, let w and w' be the apparent weights in air, and let w_1 and w_2 be the absolute weights; so that $w=w_1(1-m)$, $w'=w_2(1-n)$, where by the laws of hydrostatics mw_1 is the weight of the air displaced by the beam supposed of homogeneous materials from which it differs very slightly, and nw_2 that displaced by the globe and appendages;

$$\text{or } m = \frac{\text{specific gravity of air}}{\text{specific gravity of the beam}} = \frac{a}{b} \text{ say;}$$

$$n = \frac{\text{specific gravity of air}}{\text{specific gravity of globe and appendages}} = \frac{a}{c} \text{ say.}$$

Here m and n are small quantities, but m much smaller than n , so that

$$\begin{aligned}\frac{w'.r'}{w.r} &= 1 + x \\ &= \frac{w_2.r'(1-n)}{w_1.r(1-m)} \\ &= \frac{w_2.r'}{w_1.r} (1 - \overline{n-m}) \text{ nearly} \\ &= \frac{w_2.r'}{w_1.r} \left\{ 1 - a \left(\frac{1}{c} - \frac{1}{b} \right) \right\};\end{aligned}$$

and the value of x will be continually changing as the value of a , the specific gravity of the air, changes, whilst the fraction $\frac{w_2.r'}{w_1.r}$ remains constant, and the changes in b and c are almost imperceptible in comparison with those of a : or θ , with the position of equilibrium, will continually change with the density of the atmosphere.

The degree of sensibility may be any that is wished, provided weights are added to, and taken away from the end B, which weights might be very conveniently laid upon the plate containing the agate plane. In some trials I had the index moving through 40° with $\frac{1}{2}$ grain difference in the weight hanging from B; and this is equivalent to a change of about one inch in the height of the barometer, or between 16° and 17° of Fahrenheit's thermometer.

When changes in the density of the air are required to be found which are not dependent solely on temperature and pressure, but also on occasional admixtures in the air surrounding the balance, we have to compare its indications with those of the other named instruments, and it is needless to have a greater sensibility than theirs. Now the best barometers read only to one-thousandth of an inch in the height of the mercurial column, and the best thermometers can seldom be depended upon to one-hundredth of a degree Fahrenheit; so that if $\frac{1}{2}$ a grain added at B cause the index to move through 10° of arc, and we read the vernier to $\frac{1}{2}$ minutes, we have an accuracy greater than either of the other named instruments, and one which is sufficient for our experiments. In this case the scale of 60° will suffice for the changes which occur in this climate, without need of weights in addition.

The following table contains the last series of observations which I have made previous to the instrument being finished, with some additions. The thermometer inclosed in the lantern was a good one, but not the one intended to be used, which was not ready; it was read with a reading microscope, as was also the aërometric balance. The instrument was placed in an upper room facing the west, in which no fire was lighted. The barometer was a good aneroid one, with an attached thermometer. I have not thought it necessary to give the readings of these, but only the height of the barometric column reduced to a temperature of 32°.

The column of the densities is calculated from the formula

$$\rho = \frac{p}{k(1 + \alpha\theta^{\circ})}$$

with unity as the density for 32° temperature and 30 inches barometric pressure, taking $\alpha = \frac{1}{490}$ for comparison with the aërometric balance. Although the changes take the same direction, that is, greater buoyancy is indicated when there was greater calculated density, yet the changes are not proportional; and on comparing different parts of the series, we see remarkable differences. Observations of the *wet bulb* thermometer might have enabled us to explain some of these, by the hygrometric changes going on; but if any remained, they would indicate changes in the composition of the air of the room.

When Messrs. Watkins and Hill have got the construction of the aërometric balance perfected, I should feel great interest in the results obtained in different parts of the country, but must leave the observations to others with better opportunities and more time, and rest satisfied with having completed the less important task of designing and superintending the constructions of the means of observation.

The observations of the table have a point of interest in having been taken through one period of storm, and another of dark but high fog.

Date. 1850.	Hour of ob- servation.	Barome- ter cor- rected to 32° temp.	Thermo- meter in the lan- thorn.	Density of the air from $\rho = \frac{p}{h(1 + \alpha\theta)}$	Reading of the aero-me- tric ba- lance.	Remarks.
April 12.	h m	in.	°		°	
	8 7 A.M.	29.55	55.5	.94257	+2 3	Rain, foggy.
13.	3 18 P.M.	29.72	60.9	.93870	3 35	
	8 5 A.M.	29.83	55.3	.95185	1 3	
	11 25	29.83	56.1	.95045	1 3	Dark, but high fog.
	11 34	29.83	56.4	.94993	1 8	Wind, lighter.
	7 40 P.M.	29.73	57.2	.94536	1 38	Dull, rainy.
	11 55	29.67	55.5	.94639	1 18	The same.
15.	7 55 A.M.	29.43	54.1	.94115	1 33	Dull, cloudy.
	3 10 P.M.	29.26	59.7	.92618	4 13	Has rained, now sunshine.
	11 37	29.22	57.0	.92948	3 29	Clear, starlight.
	8 5 A.M.	29.12	54.6	.93039	3 4	Wind high, with rain.
	2 0 P.M.	29.05	55.2	.92713	3 9	Storm and rain.
	3 55	29.60	55.5	.92502	3 37	High wind, sunshine.
	5 20	29.01	55.9	.92466	3 56	Very high wind.
	11 10	29.16	54.8	.93132	3 7	High wind.
17.	8 10 A.M.	29.41	53.3	.94190	2 16	Bright, strong wind.
	1 35 P.M.	29.50	58.5	.93582	3 13	Fair, sunshine, some wind.
	11 10	29.69	59.2	.94065	3 2	Starlight.
	8 6 A.M.	29.86	54.6	.95403	0 52	Bright sunshine.
18.	3 0 P.M.	30.02	63.2	.94423	3 52	The same.

IX. *Experimental Researches in Electricity.—Twenty-third Series.* By MICHAEL FARADAY, Esq., D.C.L., F.R.S., *Fullerian Prof. Chem. Royal Institution**.

§ 29. *On the polar or other condition of diamagnetic bodies.*

2640. **F**OUR years ago I suggested that all the phænomena presented by diamagnetic bodies, when subjected to the forces in the magnetic field, might be accounted for by assuming that they then possessed a polarity the same in kind as, but the reverse in direction of, that acquired by iron, nickel and ordinary magnetic bodies under the same circumstances (2429. 2430.). This view was received so favourably by Plücker, Reich and others, and above all by W. Weber†, that I had great hopes it would be confirmed; and though certain experiments of my own (2497.) did not increase that hope, still my desire and expectation were in that direction.

2641. Whether bismuth, copper, phosphorus, &c., when

* From the Philosophical Transactions for 1850, part i.; having been received by the Royal Society January 1, and read March 7 and 14, 1850.

† Poggendorff's *Annalen*, January 7, 1848; or Taylor's *Scientific Memoirs*, vol. v. p. 477.